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PUBLIC WORKS CANADA'S DREDGING  
OPERATIONS AT THE MOUTH OF THE  
RED RIVER

ENVIRONMENTAL EFFECTS

by

Domenico Povoledo 1990

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Environmental Protection  
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**PWC DREDGING OPERATIONS: A RECONNAISSANCE OF SEDIMENTARY  
METALLIC AND ORGANIC TOXIC SUBSTANCES IN LAKE WINNIPEG AT THE  
MOUTH OF THE RED RIVER**

**INTRODUCTION**

Routine dredging operations are performed by Public Works Canada (PWC), at the request of various clients, downstream from the city of Winnipeg, in order to ensure navigability of the Red River and Lake Winnipeg and for recreational, fisheries and commercial activities (Public Works Canada, 1987). The selection of dredging sites for 1987 included 12 sites (Figure 1). A detailed description of each site can be found in Appendix 1. Three of the sites are in the Red River and nine in the lake or at other tributary mouths. These sites have been selected during the past several decades and some, e.g. the site at the mouth of the Red River, since the turn of the century. This site, No. 8 (Figure 1), is dredged yearly. About 49 per cent of the total amount of the sediment dredged by PWC comes from it (Table 1). Other sites have been dredged with random frequency. For example, dredging of site 3 (Icelandic River) began in 1978 and now is dredged yearly. Sites 1 (Arnes) and 2 (George Island) were last dredged in 1984 and 1985, respectively. In 1987 only at sites 3 and 8 was a comparatively sizable amount of sediment dredged (Table 1).

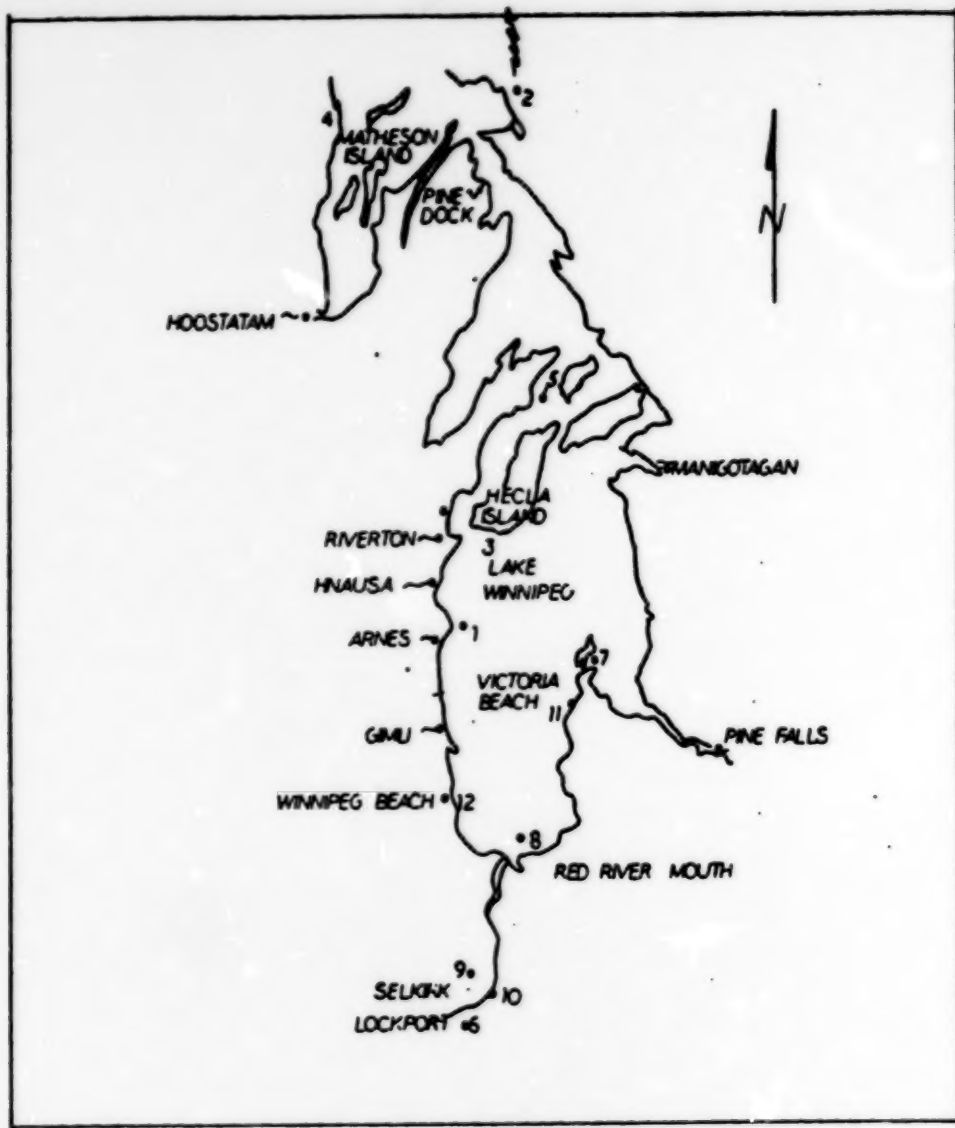


FIGURE 1. PUBLIC WORKS CANADA DREDGING SITES 1987

TABLE 1 - PWC 1987 DREDGING PROGRAM

| LOCATION                | DREDGE GRADE<br>Ø | TOTAL, m <sup>3</sup> |
|-------------------------|-------------------|-----------------------|
| 1. Arnes                | 205.0             | 2,000                 |
| 2. George<br>Island     | 214.5             | 500                   |
| 3. Icelandic<br>River   | 215               | 30,000                |
| 4. Kinnow Bay           | 214.3             | 4,500                 |
| 5. Little<br>Grindstone | 215.2             | 500                   |
| 6. Lockport             | 213.7             | 1,000                 |
| 7. Matheson<br>Island   | 214.3             | 2,500                 |
| 8. Red River<br>Mouth   | 213.4             | 48,000                |
| 9. Selkirk<br>Drydock   | 213.7             | 750                   |
| 10. Selkirk<br>Slough   | 213.7             | 5,000                 |
| 11. Victoria<br>Beach   | 214.3             | 1,000                 |
| 12. Winnipeg<br>Beach   | 215.0             | 3,000                 |
| TOTAL                   |                   | 98,750                |

## STUDY OBJECTIVES AND AREA

The purpose of this study was to determine in a preliminary manner the level of inorganic and organic contaminants present in the dredged sediment at the mouth of the Red River in order to establish whether additional sampling is warranted for purposes of assessing the environmental acceptability of current PWC dredging practices. The study area (Figures 1 and 3) is the mouth of the Red River where it enters Lake Winnipeg.

Essential data on Lake Winnipeg (Figure 2) and its watershed have been measured and/or gathered by Brunskill and his collaborators (1979, 1980). The lake has an overall surface area of 23,750 km<sup>2</sup>, imbedded in precambrian (east coast) and ordovician (west coast) formations. It represents a shallow remnant of the post-glacial Lake Agassiz. Pollution, if any, and moderate dredging are most likely confined to the south basin (Figure 2) and historically should not have begun earlier than the year 1812 when settlers colonized the Town of Selkirk on the Red River. The south basin represents 11.7 per cent of the lake's surface area, accounting for 2,780 km<sup>2</sup>. It has a mean depth of 9.7 m for  $2.7 \times 10^{10}$  m<sup>3</sup>, 9.5% of the overall lake's volume,  $2.84 \times 10^{11}$  m<sup>3</sup>.

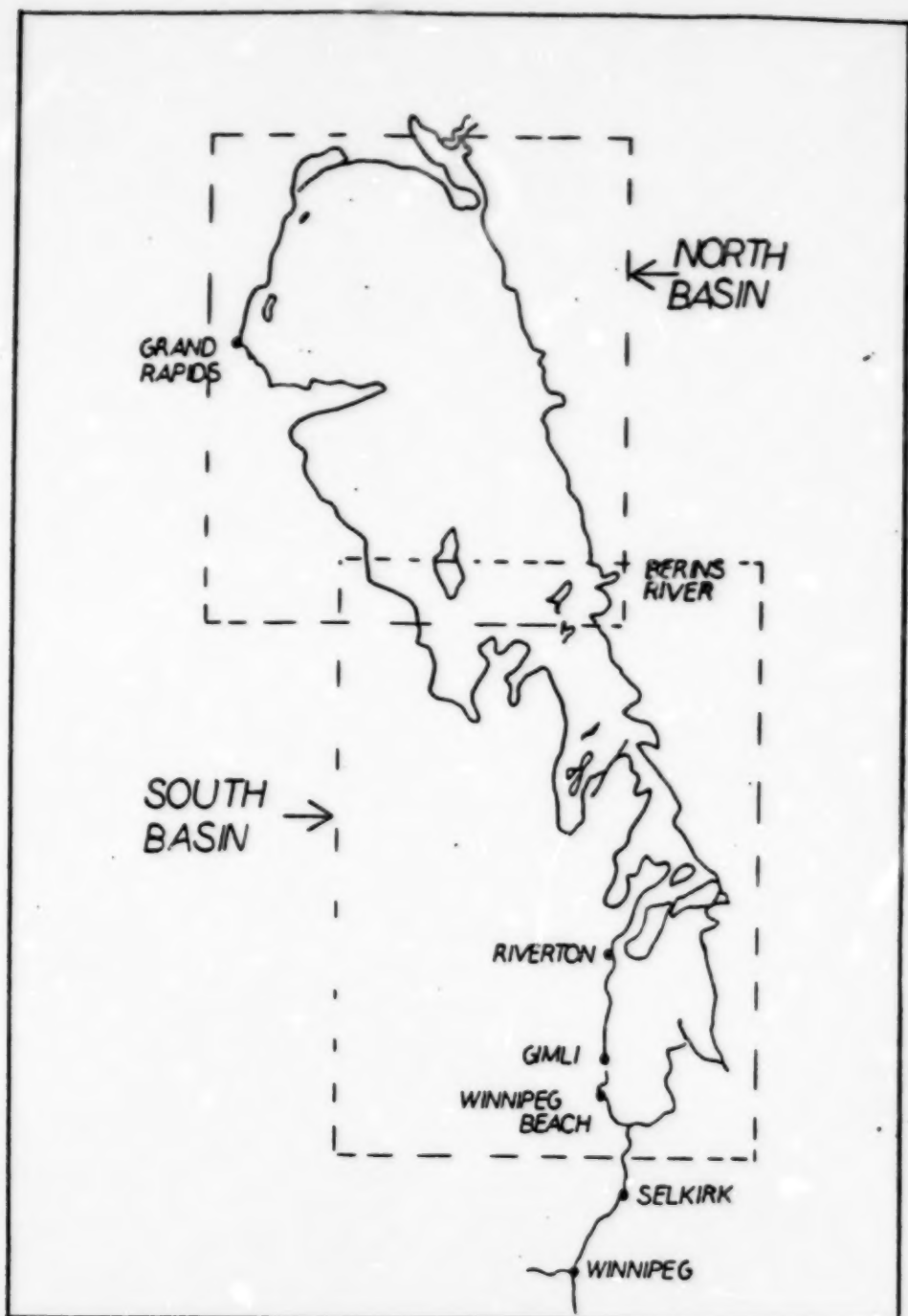


FIGURE 2. LAKE WINNIPEG MAP



The water budget of the south basin is secured by the input of the Winnipeg River (72.52%), the Red River (15.9%) and other small precambrian and sedimentary drainages, as well as direct precipitation. The total average annual input to the basin is  $5.0 \times 10^{10} \text{ m}^3$ .

#### METHODS

Two sets of sampling were performed, in June before and in August after 1987 dredging operations (Table 2 and Figure 3). Sampling sites within the channel were close to sextant located navigation buoys. Each set consisted of 6 samples, 3 collected about 700 m from the dredging channel, and 3 within the area of dredging. Spoils were deposited in the lake 220 m east of the cut (PWC, 1987). For sake of brevity, the samples have been referred to as "control" (away from the dredging) and "test" (in the dredging channel). Table 2 shows some other standard measurements as well which were taken in the field on the sediment and on the overlying water.

Since collection of undisturbed sediments for limnological and oceanographic work is better if done by coring, preliminary test sampling was conducted with a  $56 \text{ cm}^2$  cross-sectional area gravity corer. The wide sectional area would have permitted collection of large volumes of specific sediment strata. Apparently the shallow depth of the overlying water (2.4 to 4.6 m, Table 2) was inadequate for the core sampler to develop the

**TABLE 2 - TIME AND LOCATION OF SAMPLING**  
**BASIC STATIONS' PARAMETERS**

| SAMPLING<br>STATION  | PERIOD<br>SINCE<br>PREVIOUS<br>DREDGING | DEPTH<br>m | pH of<br>SEDIMENT | pH of<br>WATER | SURFACE<br>TEMPERATURE<br>Celsius |
|----------------------|-----------------------------------------|------------|-------------------|----------------|-----------------------------------|
| D.C. NORTH<br>END    |                                         |            |                   |                |                                   |
| 18.06.87             | 1 week                                  | 4.6        | 6.4               | 8.4            | 23.7                              |
| 10.08.87             | 1 month                                 | 4.6        | 6.7               | 7.7            | ---                               |
| D.C.<br>MIDDLE       |                                         |            |                   |                |                                   |
| 10.06.87             | 9 months                                | 3.35       | 6.4               | 8.5            | 23.6                              |
| 18.08.87             | 1 month                                 | 4.3        | 6.6               | 7.8            | ----                              |
| D.C. SOUTH<br>END    |                                         |            |                   |                |                                   |
| 18.06.87             | 9 months                                | 4.3        | 6.7               | 7.1            | 23.8                              |
| 18.08.87             | 1-2 weeks                               | 4.3        | 6.6               | 7.8            | ----                              |
| CONTROL<br>S.W.      |                                         |            |                   |                |                                   |
| 18.06/87             | ---                                     | 3.2        | 6.5               | 6.8            | 24.0                              |
| 18.08.87             | ---                                     | 3.3        | 6.5               | 7.8            | ----                              |
| CONTROL<br>W.C.      |                                         |            |                   |                |                                   |
| 18.06.87             | ---                                     | 4.1        | 6.8               | 6.8            | 23.5                              |
| 18.08.87             | ---                                     | ---        | ---               | ---            | ----                              |
| CONTROL<br>S.W.      |                                         |            |                   |                |                                   |
| 18.06.87             | ---                                     | 4.1        | 6.8               | 6.8            | 23.5                              |
| 18.08.87             | ---                                     | 4.4        | 6.4               | 7.8            | ----                              |
| CONTROL<br>W.S. - D. |                                         |            |                   |                |                                   |
| 18.06.87             | ---                                     | ---        | ---               | ---            | ----                              |
| 18.08.87             | ---                                     | 2.4        | 7.3               | 7.5            | ----                              |

necessary momentum prior to impact with the sediment to obtain a sufficiently long core. Furthermore, as the sediment texture was mostly sand (Table 3), the core was not retained in the sampler during retrieval.

As a result an Ekman dredge was utilized. Although loss of fines is a potential problem with the Ekman dredge, this phenomenon was minimized as a result of the short retrieval distance where sampling occurred. In order of suitability, Ponar followed by Ekman were two dredge types recommended for grab sampling of sediments (Arctic Laboratories, 1985). As a Ponar grab sampler was not readily available and a proper sampling platform (i.e. winch equipped ship) was not assured, an Ekman dredge was utilized.

The sediment samples were poured into large mouth plastic containers as recommended by the laboratory that performed the inorganic analyses. The jars were screw-capped on-board and prepared for shipment in styrofoam coolers and chilled with ice. Chilling was repeated the same day just before air shipment by replacing the previously melted ice. Delivery to the Environmental Protection analytical laboratory in Edmonton was assured for the morning after collection: not more than 24 hours elapsed between sampling and delivery to the laboratory. Samples were then frozen and preserved until just prior to analysis. Before the collection jars were capped, the apparent sediment pH was measured. Both electrodes, the indicating glass and reference calomel, of the portable potentiometer

were dipped, during the measurement in the field, in the very watery suspension overlying the sediment sample in the jar (Spiegler and Wyllie, 1956). The assumption was made that no strong  $[H^+]$  gradient exists between the water and the surface of the particulate solids as pointed out by Spiegler and Wyllie (l.c.).

Lake water composite samples were collected at the same time with a Van Dorn sampler. Composite mixtures were obtained by pooling 3 samples: approximately, one drawn at 1 m below the surface whose temperature was measured, one at middle depth, and the third 0.3 m above the bottom. Depth was measured with a ruled cord. The pH of the composite sample was measured with the battery operated pH meter equipped with glass-calomel electrodes. In this way, any substantial departure from neutrality in these poorly buffered precambrian waters was checked. Acidity of a pH of 5 or less may result in changes in chemical composition (Vollenweider, 1963; Marchetti, 1979; Bonacina, 1970; Bonacina, Calderoni and Mosello, 1988).

Each sample was distributed into two 1 L plastic jars. Preservation of one jar was made by adding 1.5 ml of concentrated  $HNO_3$  for the analysis of heavy metals. The same preservative plus 10 ml of 5 per cent aqueous potassium dichromate were added to the second sub-sample for the measurement of total mercury. Two more composite specimens of 4 L each were poured in brown plastic bottles, preserved with 30 ml of dichloromethane and used for the gas-chromatographic analysis

of organic contaminants (herbicides, insecticides and PCBs). Phthalates contamination from the plastic containers was deemed inconsequential. All organic xenobiotic compounds<sup>1</sup> searched except possibly Carbofuran can be detected by Electron Capture, by far the most sensitive GC detector for pesticide mixtures (EPA, 1979b). The U.S. Environmental Protection Agency recommends not to use plastic containers if this detector will be the one of choice. In our analyses a Mass Spectrometer coupled to the GC was utilized.

Other analytical techniques utilized have been those recommended by the U.S. EPA (1983) i.e. Atomic Absorption, Direct Aspiration. Mercury was analyzed by the Cold Vapour Atomic Absorption method. Loss on Ignition (LOI) was measured on sediments by the technique described by APHA, AWWA, WPCF (1985) at 550° C. Particle size distribution was determined by the Hydrometer Method of the Canadian Soil Science Society (1978). The sediment samples collected by Brunskill et al. in 1979 have been analyzed for metals by Allan (Allan and Brunskill 1977; Brunskill et al. 1979) by Radio Frequency Plasma Emission Spectroscopy.

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1. The term 'xenobiotic compound' should be used for "all compounds which are released in any compartment of the environment by the action of man and thereby occur in a concentration in this or another compartment of the environment that is higher than 'natural'" Hutzinger and Veerkamp 1981, quoted by Leisinger, 1983.

## RESULTS

Two groups of analyses were performed. For the first group the following variables were measured: on the wet sediment, Loss on Ignition (LOI); % moisture (MOI %); and, on the dry sediment, % Sand; % Silt; % Clay; Al; Cd; Ca; Cr; Cu; Fe; Pb; Hg; Mg; Ni; Zn. The same chemical parameters were measured on the composite water samples. For the second group, PCBs, the insecticides Lindane and Carbdofuran, and the herbicides Trifluralin, Trialate, MCPA, Dicamba, Diclofop-methyl were chosen for analysis. These pesticides are frequently and abundantly utilized in the catchment area of the lower Red River (Todd, 1987). These compounds were selected as indicators of air-borne or runoff-bound organic, xenobiotic contamination because they do not naturally occur in the environment. Analyses were not conducted for hydrocarbons as there are no background data on naturally occurring hydrocarbons upon which to compare more recent data. The data are summarized in Tables 3, 4a, 4b, 5a and 5b. As already stated, the "control" stations were approximately 700 m from the dredging cut. The "test" stations were within the cut. One should emphasize that "control" and "test" are merely descriptive terms for the site of sampling. Incidental differences between controls and tests can be the consequence of horizontal movements of the bottom (vide infra).

TABLE 3 - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL AND TEST 1987 JUNE AND AUGUST SAMPLES

| LOI<br>%               | MOI<br>% | SAN<br>% | SIL<br>% | CLA<br>% | Al<br>g/100g | Ca<br>g/100g | Fe<br>g/100g | Mg<br>g/100g | *          |
|------------------------|----------|----------|----------|----------|--------------|--------------|--------------|--------------|------------|
| 3.74                   | 38.80    | 67.00    | 15.00    | 18.00    | 5.13         | 4.8          | 1.73         | 1.48         | 1.JUN.87.C |
| 5.23                   | 24.90    | 92.00    | 4.00     | 4.00     | 3.77         | 3.73         | 0.76         | 0.87         |            |
| 5.28                   | 48.00    | 14.00    | 58.00    | 28.00    | 6.84         | 5.22         | 2.64         | 2.41         |            |
| 1.57                   | 39.40    | 71.00    | 16.00    | 13.00    | 4.87         | 5.07         | 1.52         | 1.81         | 2.AUG.87.C |
| 5.59                   | 57.40    | 10.00    | 44.00    | 46.00    | 7.48         | 5.31         | 2.92         | 2.44         |            |
| 1.20                   | 30.40    | 86.00    | 8.00     | 6.00     | 4.23         | 4.32         | 1.04         | 0.99         | 3.JUN.87.T |
| 9.40                   | 64.20    | 20.00    | 38.00    | 42.00    | 6.66         | 4.71         | 2.62         | 1.99         |            |
| 3.71                   | 44.00    | 66.00    | 20.00    | 14.00    | 4.81         | 4.76         | 1.83         | 1.30         |            |
| 6.68                   | 51.90    | 30.00    | 50.00    | 20.00    | 5.98         | 5.06         | 2.37         | 1.92         |            |
| 6.69                   | 57.60    | 20.00    | 46.00    | 34.00    | 6.39         | 5.13         | 2.59         | 2.14         | 4.AUG.87.T |
| 5.70                   | 58.30    | 38.00    | 52.00    | 10.00    | 5.64         | 5.09         | 2.29         | 1.83         |            |
| 5.73                   | 53.00    | 28.00    | 50.00    | 22.00    | 6.45         | 5.07         | 2.77         | 2.01         |            |
| DESCRIPTIVE STATISTICS |          |          |          |          |              |              |              |              |            |
| X                      | 5.03     | 47.25    | 33.42    | 21.42    | 5.69         | 4.86         | 2.09         | 1.76         |            |
| CV%                    | 44.76    | 25.50    | 57.94    | 63.60    | 19.98        | 9.17         | 33.79        | 28.84        |            |

TABLE 3: Last column: 1,2,3 and 4 represent the time of collection (June and August) and the kind ("Control" & "Test") of the samples analyzed in these rows.

TABLE 3 - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL AND TEST JUNE AUGUST 1987 SAMPLES continued

| Cd<br>mg/kg | Cr<br>mg/kg | Cu<br>mg/kg | Pb<br>mg/kg | Hg<br>mg/kg | Ni<br>mg/kg | Zn<br>mg/kg |            |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| 0.250       | 56.90       | 15.3        | 14.80       | 0.062       | 16.70       | 58.40       | 1.JUN.87.C |
| 0.250       | 28.40       | 4.80        | 6.80        | 0.024       | 6.25        | 23.70       |            |
| 0.250       | 91.50       | 27.80       | 18.90       | 0.084       | 25.90       | 100.40      |            |
| 0.250       | 39.30       | 10.70       | 10.70       | 0.076       | 12.60       | 43.50       | 2.AUG.87.C |
| 0.250       | 80.50       | 30.20       | 18.20       | 0.084       | 28.30       | 113.10      |            |
| 0.250       | 28.80       | 7.50        | 9.00        | 0.041       | 9.00        | 37.10       |            |
| 0.250       | 94.20       | 23.30       | 23.80       | 0.085       | 28.10       | 103.50      | 3.JUN.87.T |
| 0.250       | 62.20       | 5.80        | 18.60       | 0.086       | 19.40       | 62.30       |            |
| 0.250       | 79.10       | 29.40       | 23.10       | 0.198       | 28.00       | 92.00       |            |
| 0.250       | 82.60       | 30.00       | 22.20       | 0.138       | 27.00       | 96.00       | 4.AUG.87.T |
| 0.250       | 57.80       | 23.30       | 22.30       | 0.116       | 25.30       | 81.60       |            |
| 0.250       | 69.40       | 27.10       | 20.60       | 0.231       | 8.60        | 98.40       |            |

DESCRIPTIVE STATISTICS

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| X     | 0.250 | 64.22 | 19.60 | 17.42 | 0.102 | 21.26 | 75.83 |
| C.V.% | ---   | 35.60 | 51.50 | 33.28 | 59.53 | 38.60 | 39.19 |

TABLE 3: last column: 1,2,3 and 4: represent the time of collection, (June and August) and the kind ("Control" & "Test") of the samples analyzed in these rows.

TABLE 4a - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL, JUNE 1987

|      | LOI<br>% | MOI<br>% | SAM<br>% | SIL<br>% | CLA<br>% | Al<br>g/100g | Ca<br>g/100g | Fe<br>g/100g | Mg<br>g/100g |
|------|----------|----------|----------|----------|----------|--------------|--------------|--------------|--------------|
| MEAN | 4.75     | 37.83    | 57.67    | 25.66    | 16.67    | 5.25         | 4.61         | 1.71         | 1.59         |
| %(*) | 89.62    | 80.06    | 127.67   | 76.78    | 77.82    | 92.27        | 94.85        | 81.82        | 90.34        |

TABLE 4a - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL (continued) JUNE 1987

|      | Cd<br>mg/kg | Cr<br>mg/kg | Cu<br>mg/kg | Pb<br>mg/kg | Hg<br>mg/kg | Ni<br>mg/kg | Zn<br>mg/kg |
|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| MEAN | 0.25        | 58.93       | 15.97       | 13.50       | 0.03        | 16.28       | 60.83       |
| %(*) | ---         | 91.71       | 81.48       | 77.51       | 29.41       | 76.57       | 80.22       |

\*\*\*\*\*  
 %(\*) Normalization: mean of data from samples collected outside the dredging channel ("controls") in June x 100 and divided by the means of table 3.  
 \*\*\*\*\*

TABLE 4b - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL AUGUST 1979

|       | LOI   | MOI   | SAM    | SIL   | CLA    | Al     | Ca     | Fe     | Mg     |
|-------|-------|-------|--------|-------|--------|--------|--------|--------|--------|
| %     | %     | %     | %      | %     | %      | g/100g | g/100g | g/100g | g/100g |
| MEAN  | 2.79  | 42.40 | 55.67  | 22.67 | 21.67  | 5.53   | 4.92   | 1.83   | 1.75   |
| % (*) | 55.41 | 89.60 | 123.26 | 67.84 | 101.18 | 97.24  | 101.19 | 87.60  | 99.10  |

TABLE 4b - LAKE WINNIPEG SEDIMENT COMPOSITION - CONTROL (continued) \*

|      | Cd    | Cr    | Cu    | Pb    | Hg    | Ni    | Zn    |
|------|-------|-------|-------|-------|-------|-------|-------|
| g/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| MEAN | 0.25  | 49.53 | 16.13 | 12.63 | 0.067 | 16.63 | 64.56 |
| %(*) | ---   | 77.12 | 82.29 | 72.52 | 65.69 | 78.21 | 85.14 |

(\*) % Normalization: mean of data from samples collected outside the dredging channel ("control") in June (Table 4a) and in August (Table 4b) x 100 and divided by the means of Table 3.

TABLE 5a - LAKE WINNIPEG SEDIMENT COMPOSITION - TEST STATIONS JUNE 1967

| LOI<br>% | MOI<br>% | SAN<br>% | SIL<br>% | CLA<br>% | Al<br>g/100g | Ca<br>g/100g | Fe<br>g/100g | Mg<br>g/100g |
|----------|----------|----------|----------|----------|--------------|--------------|--------------|--------------|
| 6.60     | 53.37    | 38.67    | 36.00    | 25.33    | 5.82         | 4.84         | 2.27         | 1.74         |
| 131.21   | 112.95   | 85.61    | 79.70    | 118.25   | 102.28       | 99.59        | 108.61       | 98.86        |
| MEAN     |          |          |          |          |              |              |              |              |
| %(*)     |          |          |          |          |              |              |              |              |

TABLE 5a - LAKE WINNIPEG SEDIMENT COMPOSITION - TEST STATIONS (continued)

|      | Cd<br>mg/kg | Cr<br>mg/kg | Cu<br>mg/kg | Pb<br>mg/kg | Hg<br>mg/kg | Mn<br>mg/kg | Zn<br>mg/kg |
|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|      | 0.250       | 78.50       | 19.50       | 21.83       | 0.123       | 25.17       | 85.98       |
|      | ---         | 122.24      | 99.45       | 125.31      | 120.588     | 118.39      | 113.36      |
| MEAN |             |             |             |             |             |             |             |
| %(*) |             |             |             |             |             |             |             |

TABLE 5b - LAKE WINNIPEG SEDIMENT COMPOSITION - TEST STATIONS AUGUST 1987

|      | LOI    | MOI    | SAM   | SIL    | CLA    | Al     | Ca     | Fe     | Mg     |
|------|--------|--------|-------|--------|--------|--------|--------|--------|--------|
|      | %      | %      | %     | %      | %      | g/100g | g/100g | g/100g | g/100g |
| MEAN | 6.00   | 56.3   | 28.66 | 49.33  | 22.00  | 6.16   | 5.09   | 2.54   | 1.99   |
| %(*) | 119.28 | 119.15 | 63.45 | 147.60 | 102.71 | 108.26 | 104.73 | 121.53 | 113.07 |

TABLE 5b - LAKE WINNIPEG SEDIMENT COMPOSITION - TEST STATIONS (continued)

|       | Cd     | Cr     | Cu     | Pb      | Hg     | Ni     | Zn    |
|-------|--------|--------|--------|---------|--------|--------|-------|
|       | mg/kg  | mg/kg  | mg/kg  | mg/kg   | mg/kg  | mg/kg  | mg/kg |
| 0.250 | 69.93  | 26.80  | 21.70  | 0.162   | 26.97  | 92.00  |       |
| ---   | 108.89 | 136.73 | 124.57 | 158.823 | 126.86 | 121.32 |       |

%(\*) Normalization: means of data of samples collected within the dredging channel ("tests") in June (Table 5a) and in August (Table 5b) x 100 and divided by the means of Table 3.

In table 6a some statistical results from Brunskill et al. 1979 are reported after minor elaboration. These data can be regarded as background values to which the results of this survey can be compared. Values referred in Tables 6b and 6c were calculated from the same source and refer to homogenized samples of the top 25 cm of sediment from 11 stations collected with a gravity corer (Table 6b) and from the remaining core portion, from 30 to 75 cm (Table 6c). In Table 6a the values of surface sediment samples (ca. 20 cm deep) collected by grab dredging with an Ekman dredge were obtained from 50 stations distributed all over the lake (Figure 4 stations 9, 11, 13, 16, 19, 20, 22, 24, 28, 29, 30, 32, 36, 37, 38, 40, 42, 43, 44, 45, 46, 49, 56, 58 have not been analyzed; stations 61, 64, 68, 69 have been analyzed but are not illustrated in the figure). It has been ascertained by Brunskill et al., on the basis of the analysis of small cross-sectional core slices, that the composition of the first 0 to 25 cm sediment at 11 stations (Table 6b) of the 75 cm long cores is not markedly dissimilar from the composition (Table 6c) of the following, deeper portion from 30 cm to the lowest portion of the cores and that their age can be traced to the last two centuries. The 50 Ekman grab samples and the 11 gravity cores collected by Brunskill et al. were from

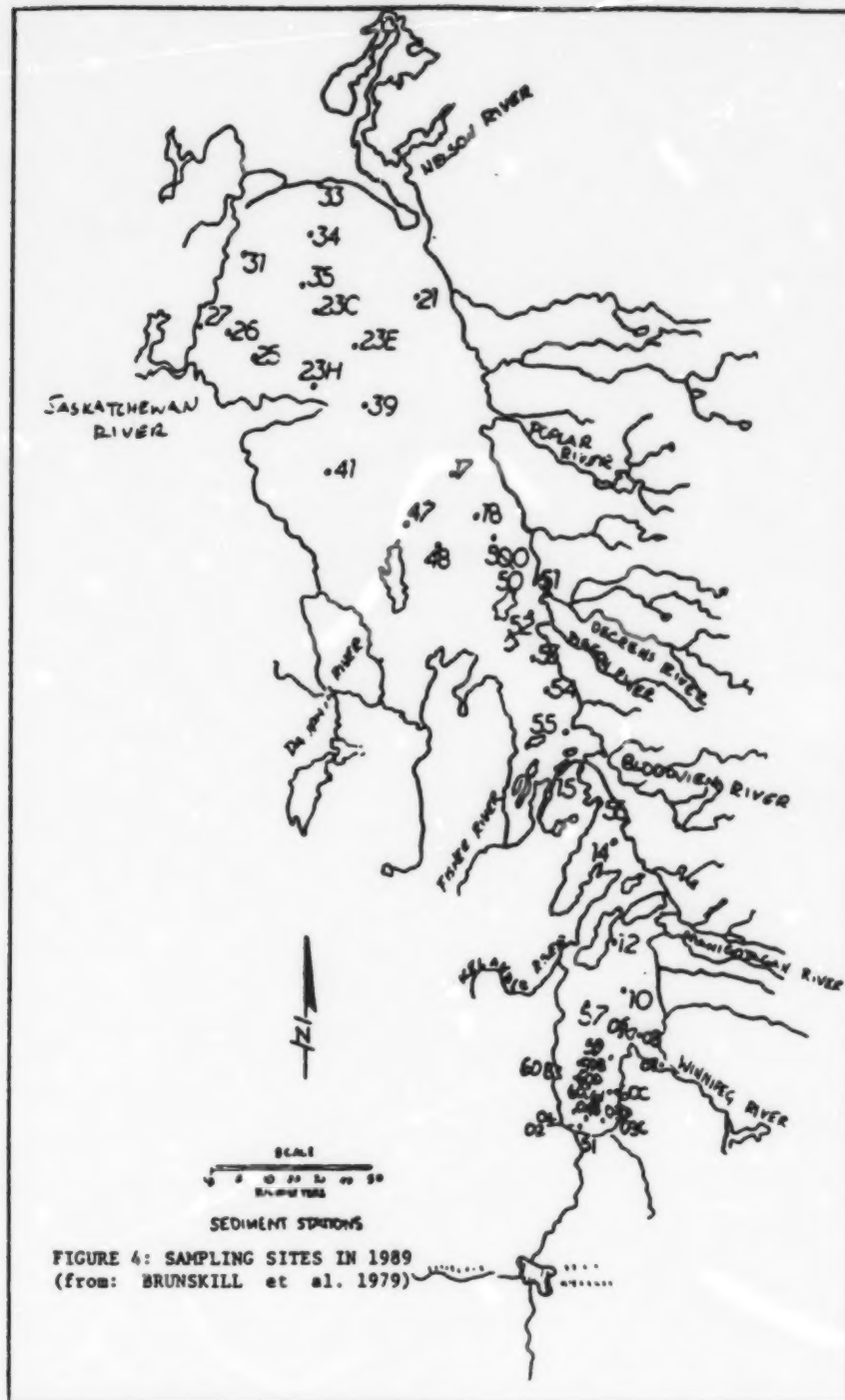


TABLE 6a - SURFACE SEDIMENT (0-20 cm) 1969 SAMPLES - DESCRIPTIVE STATISTICS  
(n = 50 FOR EACH METAL 50- STATIONS)

|     | Al        | Ca    | Fe    | Mg    | Cd    | Cr     | Cu    | Pb     | Ni    | Zn     |
|-----|-----------|-------|-------|-------|-------|--------|-------|--------|-------|--------|
|     | g/100g    |       |       |       |       |        |       |        |       |        |
|     | mg/1,000g |       |       |       |       |        |       |        |       |        |
| X   | 2.73      | 2.685 | 2.569 | 2.09  | 2.02  | 137.79 | 37.49 | 39.37  | 55.18 | 189.60 |
| SD  | 1.21      | 1.923 | 0.670 | 0.85  | 0.45  | 33.20  | 10.80 | 45.58  | 11.74 | 2.69   |
| CV% | 16.48     | 71.65 | 26.09 | 40.70 | 22.26 | 24.15  | 28.81 | 115.78 | 21.27 | 17.24  |

Data from Brunskill et al., 1979.

TABLE 6b - SEDIMENT CORES (0-25 cm) 1969 SAMPLES - DESCRIPTIVE STATISTICS  
(n = 33 FOR EACH METAL FROM 11 STATIONS)

|     | Al        | Ca    | Fe    | Mg    | Cd | Cr     | Cu    | Pb    | Ni    | Zn     |
|-----|-----------|-------|-------|-------|----|--------|-------|-------|-------|--------|
|     | g/100g    |       |       |       |    |        |       |       |       |        |
|     | mg/1,000g |       |       |       |    |        |       |       |       |        |
| X   | 25.07     | 1.86  | 2.81  | 1.45  |    | 164.57 | 41.42 | 20.65 | 60.90 | 200.04 |
| SD  | 0.92      | 0.99  | 0.57  | 0.48  |    | 21.68  | 7.23  | 6.76  | 8.66  | 25.67  |
| CV% | 11.81     | 53.54 | 20.24 | 25.45 |    | 13.20  | 17.46 | 32.74 | 14.21 | 12.83  |

Data from Brunskill et al., 1979

TABLE 6C - SEDIMENT CORES (30-75 cm) 1969 SAMPLES - DESCRIPTIVE STATISTICS  
(n = 33 FOR EACH METAL FROM 11 STATIONS)

|           | Al    | Ca    | Fe    | Mg    | Cd | Cr     | Cu    | Pb    | Ni    | Zn     |
|-----------|-------|-------|-------|-------|----|--------|-------|-------|-------|--------|
| g /100g   |       |       |       |       |    |        |       |       |       |        |
| mg/1,000g |       |       |       |       |    |        |       |       |       |        |
| $\bar{x}$ | 8.00  | 2.13  | 3.01  | 2.01  |    | 161.39 | 39.75 | 19.15 | 61.44 | 192.93 |
| S.D.      | 1.11  | 1.22  | 1.18  | 0.58  |    | 26.18  | 8.60  | 5.86  | 11.12 | 42.98  |
| CV%       | 13.63 | 57.57 | 39.31 | 28.70 |    | 16.22  | 21.64 | 30.61 | 18.10 | 22.27  |

Date from Brunskill et al. 1979.

sites distributed all over Lake Winnipeg, including many in which there is not any appreciable development of human settlements nor dredging activity. As a consequence the 1969 study results reflect natural sedimentation and the sediments reflect the geochemical and biogeochemical structure of the watersheds. The variability of data in Table 6a represents horizontal concentration with values ranging between a C.V of 16.8-115.78%. Low C.V. values are by far the most common. There is also in general a skewness toward the low values dependent from metal to metal. The data dealing with sediment cores represent horizontal and vertical variability for each metal. Both are strongly influenced by the turbulent resuspension of surficial sediments, quite likely occurring because of strong winds and currents acting on the bottom of a shallow unprotected lake. The vertical variability is linked to the history of the lake and its watershed, especially erosion and sedimentation processes.

The analytical method of determination (radio frequency plasma emission spectroscopy) has the same degree of precision, accuracy and sensitivity as similar emission or absorption spectroscopic methods (Wagemann, DOE FWI Winnipeg, personal communication).

## DISCUSSION

Sedimentation rate has been linked to annual rainfall in the catchment area of a lake. It has been shown there is an individual relationship between the annual inflowing rivers discharge and the suspended solids in each river water. As far as the Red River is concerned, the data at hand covering twelve years of observations were conducive to the formulation of the following exponential operational equation (Brunskill et al. 1980) :

$$SS = 3.41 \times 10^5 \times se^{(2.10 \times 10E-10)Q_a} \quad (r = 0.93)$$

where SS = sediment input, and  $Q_a$  represents the annual water inflow. Since the latter shows wide fluctuations from year to year, so does SS. According to the equation, the time-averaged loading from the Red River is  $1.84 \times 10^6$  T/Y, approximately 82.4 % of the total. Assuming a density of 1 and no moisture, the thickness of averaged annual addition of sediment from the Red River would be 0.66 mm. The depth of the trench excavated by PWC every year is approximately 500 times greater.

In general, early return to the statu quo in the areas dredged may be expected. In our case, direct assessment of this assumption has not been done. Infilling of the channel should

readily have occurred because the sediment surrounding the trench is not highly compacted (47 % moisture, and particles quite often comprised of sand: Table 3) and either slumps from the sides of the depression or is moved in as a result of resuspension by turbulence due to strong wind-borne waves and water currents. Although direct measurement of the rate of infilling is missing, it has been deemed that the dredging channel replenishment occurs every two years (Colp, Winnipeg PWC, personal communication).

From Tables 3, 4a, 4b, 5a and 5b it can be seen that the samples collected within the dredging channel appear to contain a moderately greater amount of metals than those collected about 700 m from the dredging cut. This variability is, however, well within the range of natural variability found by Brunskill et al., 1979, for the south basin of Lake Winnipeg. Indeed the plume of the river inflow is distributed in an area much wider than the dredging channel. Furthermore, there is even less variability between the samples, control or test, collected in June and in August.

The sample concentration of each metal, as expressed by descriptive statistics (Table 3) shows a per cent coefficient of variation between 9.17 (Ca) and 59.53 (Hg). Each metal has some degree of skewness generally to the left except for Hg.

Table 7 illustrates the data from the open water. As far as Ca and Mg are concerned (the only ones measured in both instances) the results compare with the average of type 2 lakes of north-

TABLE 7 - LAKE WINNIPEG WATER COMPOSITION - CONTROL

| Al<br>g/kg | Cd<br>mg/kg | Ca<br>g/kg | Cr<br>mg/kg | Cu<br>mg/kg | Fe<br>g/kg | Pb<br>mg/kg | Mg<br>g/kg | Hg<br>mg/kg | Ni<br>mg/kg | Zn<br>mg/kg |
|------------|-------------|------------|-------------|-------------|------------|-------------|------------|-------------|-------------|-------------|
| 1.11       | <0.02       | 48.5       | <0.05       | <0.02       | 1.00       | <0.10       | 21.7       | 0.2         | 0.03        | 0.009       |
| 1.27       | <0.02       | 51.0       | <0.05       | <0.02       | 1.19       | <0.01       | 22.8       | <0.2        | <0.03       | 0.029       |
| 1.17       | <0.02       | 46.9       | <0.05       | <0.02       | 0.99       | <0.01       | 20.1       | <0.2        | <0.03       | 0.018       |
| 1.83       | ---         | 48.8       | ---         | ---         | 1.06       | ---         | 21.5       | ---         | ---         | 0.039       |

TABLE 7bis - LAKE WINNIPEG WATER COMPOSITION - TEST SAMPLES

| Al<br>g/kg | Cd<br>mg/kg | Ca<br>g/kg | Cr<br>mg/kg | Cu<br>mg/kg | Fe<br>g/kg | Pb<br>mg/kg | Mg<br>g/kg | Hg<br>mg/kg | Ni<br>mg/kg | Zn<br>mg/kg |
|------------|-------------|------------|-------------|-------------|------------|-------------|------------|-------------|-------------|-------------|
| 1.86       | <0.02       | 59.30      | <0.05       | <0.02       | 1.56       | <0.1        | 26.4       | <0.2        | <0.03       | 0.081       |
| 2.36       | <0.02       | 59.70      | <0.05       | <0.02       | 1.72       | <0.1        | 25.7       | <0.2        | <0.03       | 0.013       |
| 3.08       | <0.02       | 54.80      | <0.05       | <0.02       | 2.34       | <0.1        | 21.9       | <0.2        | <0.03       | 0.021       |
| 2.43       | ---         | 57.93      | ---         | ---         | 1.87       | ---         | 24.67      | ---         | ---         | 0 . 0       |

central United States (Gorham et al. 1983, Table 9bis) i.e. lakes of very moderate size with low osmolarity. In water, where no traces of organic xenobiotics have been found: these should have been detected if pollution and persistence had been sufficiently pronounced.

Comparisons of data have been made between the 1987 samples (Table 3) and:

- a.) the grab-samples and cores of 1969 (Tables 6a, 6b and 6c);
- b.) the guidelines for maximum permissible sedimentary metal concentrations suggested by the Ontario Ministry of Environment and those of moderate to highly polluted values of U.S.A. EPA (Table 8) ; and
- c.) the Earth crust average metal abundance (Table 9b)

Also differences in sample results as a result of different locations and different times of sampling (1987 sampling: Tables 4a, 4b, 5a. and 5b) were examined. Mean values of each subset were normalized against the mean of the 12 samples collected in 1987. The following conclusions may be reached:

- The 1987 samples have values consistently lower than the background values. Therefore, there is no apparent anthropogenic contamination for the parameters measured.
- The background and 1987 data for Lake Winnipeg are always higher than the guideline values suggested in Table 8. Whether the latter, therefore, can be applied to Lake Winnipeg re

**TABLE 8 - GUIDELINES FOR MAXIMUM METAL CONCENTRATIONS BY U.S. EPA AND ONTARIO MINISTRY OF ENVIRONMENT**  
in mg/kg

| METAL | ONTARIO M.E. | EPA: NON POLLUTED | EPA: MODERATELY POLLUTED | EPA: HEAVILY POLLUTED |
|-------|--------------|-------------------|--------------------------|-----------------------|
| Cr    | 25           | < 25              | 25-75                    | > 75                  |
| Cd    | 1            | -                 | -                        | > 6                   |
| Cu    | 25           | < 25              | 26-50                    | > 50                  |
| Pb    | 50           | < 90              | 90-200                   | > 200                 |
| Zn    | 100          | < 90              | 90-200                   | > 200                 |

from: Mudroch, Patriquin and Fenton, 1986

TABLE 9 - COMPARISON OF METAL CONCENTRATIONS IN 1969 AND 1987  
(average values)

|         | Al     | Ca   | Fe   | Mg        | Cd    | Pb    | Cu    | Ni    | Cr     | Zn     |
|---------|--------|------|------|-----------|-------|-------|-------|-------|--------|--------|
|         | g/100g |      |      | mg/1,000g |       |       |       |       |        |        |
| 1969    |        |      |      |           |       |       |       |       |        |        |
| SAMPLES | 27.36  | 2.68 | 2.57 | 2.09      | 2.02  | 39.37 | 37.49 | 55.18 | 137.79 | 189.60 |
| 1987    |        |      |      |           |       |       |       |       |        |        |
| SAMPLES | 5.69   | 4.86 | 2.09 | 1.76      | <0.01 | 17.42 | 19.60 | 21.26 | 64.22  | 75.83  |

1969 SAMPLES: Average from 50 random statios from the whole lake. 1987 SAMPLES: Average from 12 samples from 6 stations at the mouth of the Red River.

**TABLE 9b1s - CRUSTAL ABUNDANCE OF SELECTED METALS**  
in g/kg dry matrix

| Metal     | Earth's Crust         | This Study            | 1969         |
|-----------|-----------------------|-----------------------|--------------|
|           |                       |                       | Grab Samples |
| Aluminum  | 79.90                 | 56.90                 | 27.30        |
| Calcium   | 39.50                 | 48.60                 | 26.85        |
| Iron      | 55.12                 | 20.90                 | 25.69        |
| Magnesium | 23.03                 | 17.60                 | 20.90        |
| Chromium  | 0.097                 | 0.64                  | 0.137        |
| Copper    | 0.055                 | 0.020                 | 0.037        |
| Lead      | 0.012                 | 0.017                 | 0.039        |
| Mercury   | $7.82 \times 10^{-5}$ | $1.02 \times 10^{-4}$ | ----         |
| Nickel    | 0.024                 | 0.021                 | 0.055        |
| Zinc      | 0.071                 | 0.076                 | 0.190        |

Partially adapted from Mason, 1966, Underwood, 1977 and Brownlow, 1979.

quires additional information relating the ecology of the lake on a quantitative and qualitative basis with the biogeochemistry of its sediments.

- The Lake Winnipeg sediment composition lies within the same order of magnitude as the average Earth crust.

Differences in concentration of metals between different sites reflect differences in spatial distribution which might or might not be linked at least in part to differentiated sedimentation of polluted sediments.

As far as organic contaminants are concerned, they were not found in water and only on one occasion 36 ng of carbofuran per gram of sediment was determined. This result for a strong cholinesterase inhibitor needs confirmation, however. In the same sediment samples 8 other organic xenobiotic substances have not been detected.

#### CONCLUSIONS

The above discussion is based on a limited number of samples and their elemental chemical composition and with eight xenobiotic contaminants of anthropogenic origin utilized in the watershed of the lake.

The objective of this survey was to ascertain in a preliminary manner the environmental acceptability of the PWC dredging activities. It may perhaps be worthwhile to point out its following distinctive aspects:

1.- Since the survey was preliminary, and because of time and financial constraints, the number of sites and samples analyzed was small. Therefore, the data and their manipulation may not be representative of the sediments of a very large lake. This is compounded by the discontinuities in chemical composition found in the whole lake, which are more pronounced horizontally than vertically.

2.-Lake Winnipeg sediment chemical composition exceeds the average thresholds proposed by the U.S. EPA and by the Ontario Ministry of the Environment as ecologically sound. Lake Winnipeg shows constantly higher values than those suggested by these agencies. On the other hand they are close or lower than the mean Earth crust composition, from which indeed they derive. Unusual sediment chemical composition is deemed to be a possible and important source of aquatic ecosystems imbalances even if representing only one aspect of a multifactorial process. The latter, in any event, requires short and long term thorough studies of the pelagic and benthic population autecology of the lake and of all the aspects of their development in space and time. Notable factors affecting the ecosystem are the chemical elements or compounds loading rates; the entity and rate of exchange of chemicals between the three

major compartments, namely sediment, open water and biocoenoses; and the rate of sedimentation. These characteristics of the habitat add to the lake's water masses hydrodynamics, and jointly feature the database which represents the evolving background against which the possible impact of, for example, dredging spoils deposition can be assessed.

Therefore, any acceptable environmental impact assessment requires the knowledge of many factors. The data analysed in this study are restricted to one factor only. The results support the conclusion that, when dealing with a very large turbulent lake imbedded in a given geochemical contest, they are of limited usefulness both for the impact assessment and for the selection of mitigating measures. Additional sampling and study of the same parameters does not seem warranted based on the results of this preliminary survey, unless at least incorporated in a much wider and valid framework.

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## REFERENCES

- ALLAN, R.G. and G.J. BRUNSKILL. 1977. Relative atomic variation (RAV) of elements in lake sediments: Lake Winnipeg and other Canadian Lakes, p. 108-120. *in* H.L. Golterman, (ed.) Interactions between sediments and freshwater. W.Junk B.V. Editors, The Hague, 473 p. Quoted by Brunskill *et al.* 1979.
- APHA, AWWA, WPCF. 1985. Standard methods for the examination of water and wastewater, 16th edition.
- ARCTIC LABORATORIES LTD. 1985. Sampling and analysis in the arctic marine benthic Environment. ENVIRONMENTAL PROTECTION SERVICE, YELLOWKNIFE, NWT 2 volumes.
- BONACINA, C. 1970. Il Lago d'Orta: ulteriore evoluzione della situazione chimica e della struttura della biocenosi planctonica. [Lake Orta: further evolution of the chemical situation and of the structure of the planktonic biocoenosis.]. Mem. Ist. Ital. Idrobiol., 26: 141-204.
- BONACINA, C. A. CALDERONI and R. MOSELLO. 1988. Il Lago d'Orta: evoluzione dell'inquinamento ed interventi diretti al recupero di uno dei piu' grandi laghi acidi del mondo. [Lake Orta: evolution of the pollution and interventions for the recovery of one of the largest acid lakes of the Earth.]. ACQUA-ARIA, January: 69-74.
- BROWNLOW, A.H. 1979 Geochemistry. Prentice-Hall, Publ.
- BRUNSKILL, G.J. and B.W. GRAHAM. 1979. The offshore sediments of Lake Winnipeg. Fisheries and Marine Services Manuscript Report No. 1540. 1-75.
- BRUNSKILL, G.J., S.E.M. ELLIOT and P. CAMPBELL. 1980. Morphometry, hydrology and watershed data pertinent to the limnology of Lake Winnipeg. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1556. 1-32.

- CALAMARI, D. and D. MARCHETTI. 1975. Predicted and observed acute toxicity of copper and ammonia to rainbow trout (Salmo Gairdneri Rich.). Progress in water technology, vol. 7, Nos. 3/4: 569-577 Pergamon Press.
- CANADIAN SOCIETY OF SOIL SCIENCE. 1978. Manual on soil sampling and methods of analysis.
- FOERSTNER, U., 1976. Lake sediments as indicators of heavy-metal pollution. Naturwissenschaften, 63: 465-470.
- GORHAM, E., W.E. DEAN and J.E. SANGER. 1983. The chemical composition of lakes in the north-central United States. Limnol. Oceanogr., 28: 287-301.
- HUTZINGER, O. and W. VEERKAMP, 1981. Xenobiotics with pollution potential. in Leisinger, T., A.M. Cook, R. Huetter and J. Nueesch, Eds. "Microbial Degradation of Xenobiotics and Recalcitrant Compounds". Academic Press, New York, pp 3-45.
- LEISINGER, T., 1983. I. General aspects. Microorganisms and xenobiotic compounds. Experientia, 39: 1183-1191.
- MASON, B. 1966 Principles of Geochemistry John Wiley & Sons, Publ.
- MUDROCH, P., D.PATRIQUIN and W. FENTON. 1986. Survey of bottom sediments in Hay River Harbour. Environmental Protection Service. 1-22 and 3 appendices.
- PUBLIC WORKS CANADA. 1987. Proposed Dredging Program for Lake Winnipeg and the Red River: 1987 season. PWC Program: 1.MAR/DJ-27-1.1.
- SPIEGLER, K.S. and M.R.J. WYLLIE. 1956. Electrical potential differences. in G. OSTER and A.W. POLLISTER: "Physical techniques in biological research". Vol. 2,: 301-392. Academic Press.
- TAM, K.C. and V.C. CHACKO. 1982. Toxic chemicals in the Red River delta. Manuscript.

- TODD, B., 1987. (Manitoba Agriculture: Personal communication)
- UNDERWOOD, E.L. 1977. Trace Elements in Human and Animal Nutrition.  
Academic Press, Publ.
- U.S. ENVIRONMENTAL PROTECTION AGENCY. 1979a. Methods for chemical analysis of water and wastes.  
EPA Publ. EPA-600/4-79-200, Cincinnati, Ohio.
- U.S. ENVIRONMENTAL PROTECTION AGENCY. 1979b. Manual for Analytical Quality Control for Pesticides and Related Compounds in Human and Environmental Samples. First Revision.  
EPA Publ. EPA-600/1-79-008, Cincinnati, Ohio.
- U.S. ENVIRONMENTAL PROTECTION AGENCY, 1983. Methods for Chemical Analysis of Water and Wastes. Revised March 1983.  
EPA Publ. EPA-600/4-79-020, Cincinnati, Ohio.
- VOLLENWEIDER, R.A. 1963. Studi sulla situazione attuale chimica e biologica del lago d'Orta. [Studies on the present time chemical and biological situation of Lake Orta].  
Mem. Ist. Ital. Idrobiol, 16: 21-125

## Appendix I

- Figure 1 1. Dredging sites selected by Public Works Canada for 1987. Map (see also Table 1).
1. Channel and basin as an entrance to a fish station offshore the town of Arnes.
  - 2 (not seen). Entrance channel to a harbor of refuge for fish in the southern shoreline of George Island.
  3. Excavation of a channel connecting the Icelandic River to Lake Winnipeg in vicinity of the town of Riverton.
  4. Loading area of a timber staging site in Kinwow Bay (Lake Winnipeg West Shoreline).
  5. Little Grindstone recreational and fishermen harbour clean-up.
  6. Sediment removal from the Red River, south of the Lockport lock and dam.
  7. Harbour redevelopment in the south-east shore of Matheson Island.
  8. Red River Mouth dredging site just offshore of the Red River for annual maintenance.
  9. Selkirk Drydock maintenance dredging on the left bank of the Red River, to remove silt from the Selkirk town drydock rail.
  10. Selkirk Slough maintenance dredging site for passage of commercial vessels at Selkirk, on the left Red River bank.
  11. A sand bar is removed from the south end of the wharf of Victoria Beach on the Lake Winnipeg east shoreline.
  12. Removal of an obstruction 800 m from the outer end of the breakwater at Winnipeg Beach on the west shoreline of Lake Winnipeg.

- Figure 3. Dredging channel at site 8 (Red River Mouth).
- C.1, C.2, C.3: "control" (see text) samples.  
DCN: North sample within the Dredging Cut.  
DCM: Middle sample within the Dredging Cut.  
DCS: South sample within the Dredging Cut.